Refinement of Analytical Forms of Air-Gap Relative Permeance Using a Perturbation Finite Element Method

M. V. Ferreira da Luz[1], P. Dular[2], R. V. Sabariego[2] and P. Kuo-Peng[1]
[1]GRUCAD/EEL/UFSC, Po. Box 476, 88040-970, Florianópolis, Santa Catarina, Brazil.
[2]Dept. of Electrical Engineering and Computer Science, F.N.R.S., University of Liège, Belgium.
Email: mauricio@grucad.ufsc.br

Abstract — A perturbation finite element method is used to calculate the air-gap relative permeance of electrical machines. A slot with its magnetic circuit is modeled using both an analytical model and a perturbation technique based on a magnetic vector potential formulation. The source of the perturbation problem is obtained by a reference solution, which can be either an analytical or a finite element solution. The effects of the slot geometry variation on the air-gap relative permeance are analyzed and employed to refine the initial analytical model.

I. Introduction

Electromagnetic vibration and noise are caused by generation of electromagnetic fields. Sometimes, simplified and analytical models can be used to fastly predict the sound power level spectrum generated by magnetic forces. In analytical solutions the magnetic flux density is calculated on the basis of the magnetomotive force and permeances of the air gap [1] [2]. Though, analytical equations characterizing the air-gap permeances are known for regular slots [1] [2], they must be corrected to account for different designs. To this purpose, the finite element method can be used. However, for any variation of geometrical or physical characteristics a new complete finite element computation must be performed.

The perturbation finite element method is an excellent tool to deal with this kind of geometrical variations. Benefits are particularly aimed for allowing different problem-adapted meshes and for computational efficiency due to the reduced size of each sub-problem [3]. Such a perturbation technique is here developed for the calculation of air-gap relative permeance. This approach allows correcting straightforwardly the analytical equation terms for each slot geometry variation performed.

As an application, a slot with its magnetic circuit is modeled.

II. The Air-Gap Relative Permeance

The air-gap relative permeance per unit area with slot opening effect is $\Lambda_g(\alpha) = \Lambda_{g0}\,\lambda_{g1}(\alpha)$ where the variation of the angle α with the linear coordinate x is given by $\alpha=2\pi x/(s_1 t_1)$, with s_1 the number of stator slots, t_1 the slot pitch and Λ_{g0} the permeance of smooth air gap. The component of the relative specific permeance of the air gap $\lambda_{g1}(\alpha)$ when only the stator core is slotted can be expressed in terms of a Fourier series with coefficients A_k. Each coefficient is the relative value of harmonic permeances of the air gap [1].

III. Application

A slot with its magnetic circuit is considered (Fig. 1). A reference solution is first calculated in a rectangular slot (Fig.1, *left*) with a fixed magnetomotive force. This solution serves then as a source for a perturbation problem defined in the vicinity of the slot bottom (Fig. 1, *middle*) with the reduction of slot opening at the bottom. In the reference problem the current density is defined. The source of the perturbation problem is not this current density any more but rather a part of the unperturbed magnetic flux density. Fig. 2 shows the relative permeance per unit area in the air gap.

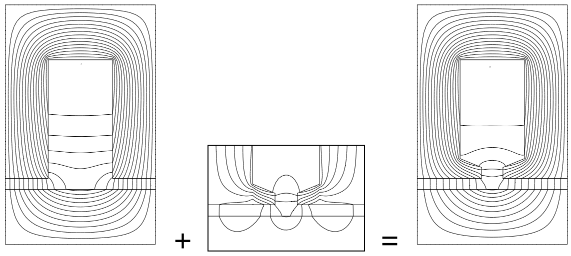

Fig. 1. Slot with its magnetic circuit: reference solution (field lines) in a rectangular slot (*left*), perturbation solution with the reduction of slot opening at the bottom (*middle*), complete (corrected) solution (*right*).

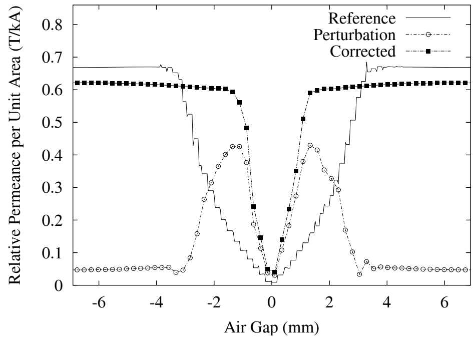

Fig. 2. Relative permeance per unit area in the air gap.

The air-gap relative permeance along the pole pitch simulated and analytically calculated will be compared considering the variation of slot geometry. In the first analysis, the study of the effects of these variations will allow to refine the analytical model through corrections of the coefficients in A_k. Then, another analysis will be extended to use the analytical solution as a source of the perturbation problem. The details regarding the definition of the (local and global) sources of the perturbation problem and the corrections of the analytical equations will be given in the extended paper.

IV. References

[1] J. F. Gieras, C. Wang, J. C. Lai, "Noise of Polyphase Electric Motors", CRC Press, Taylor & Francis Group, 2006.
[2] S. L. Nau, "Acoustic Noise of Induction Electric Motors: Causes and Solutions". 2nd International Seminar on Vibrations and Acoustic Noise of Electric Machinery, pp. 173-178, Lodz, Poland, 2000.
[3] P. Dular, R. V. Sabariego, J. Gyselinck, L. Krähenbühl, "Sub-domain finite element method for efficiently considering strong skin and proximity effects", *COMPEL*, Vol. 26, No. 4, pp. 974-985, 2007.